Department of the Navy
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DYNAMIC COEFFICIENTS OF THE MK-13 TORPEDO

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Hydrodynamics Laboratory
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Pasadena, California

Report No. E-12.20
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Approved by
Haskell Shapiro

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Introduction

The forces and moments which act on a submerged body undergoing unsteady motion can be described in terms of selected dimensionless constant hydrodynamic coefficients if the instantaneous angles of attack are kept small. To determine the values of these coefficients a model of the body can be supported from the spindle of a dynamic balance (1) in the flowing stream of a water tunnel working section. This procedure was carried out for certain coefficients on a 2-inch diameter model of the Mk-13 torpedo (Fig. 1) using the Angular Dynamic Balance in conjunction with the High Speed Water Tunnel at the California Institute of Technology, Hydrodynamics Laboratory.

Experimental Method and Analysis of Data

The method which was used to obtain the dynamic measurements was the following: Angular motion of small known amplitude and controllable frequency was imparted to a driving platform by means of a motor-driven cam. This platform is coupled to a model support spindle through a calibrated torsion spring. By allowing the spindle (and model) to rotate very freely in a bearing-seal assembly, it is possible to determine the dynamic moment reactions acting on the model. This requires knowledge of the amplitude ratio and phase angle of the ensuing motions, quantities which were determined through the aid of optical levers and a pulsing light source. The reader is directed to Reference 1 for a complete description of the equipment and experimental method employed in this study.

The dimensionless dynamic coefficients investigated in this program were $N_{\dot{r}}'$, $N_r' - N_{\dot{v}}'$, N_v', which are described in Reference 2, and

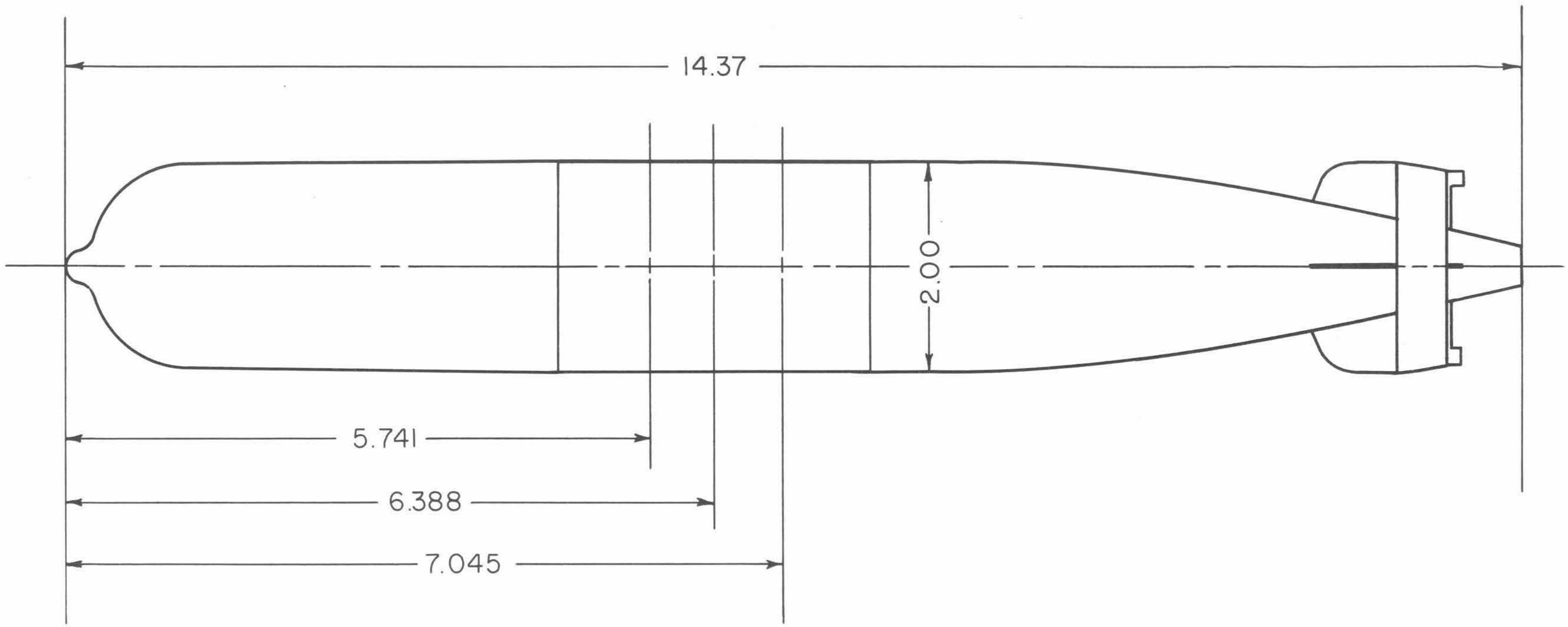

Fig. 1 - Two-inch diameter model of the Mk-13 torpedo showing the three alternative support points used in this investigation. All dimensions are in inches.

which are defined on page 9 of this report. It is to be noted that $N_r' - N_{\dot{v}}'$ is presented in a combined form rather than completely separated, as is desired. A complete analysis requires that $N_{\dot{v}}'$ be measured in a separate program using a balance which imparts a translatory motion to the model and which measures the moment reaction by means of a supplementary internal strain gage balance.

Data reduction curves for obtaining the coefficients are presented in Figures 2 and 3. Figure 2 shows the in-phase component of moment reaction and Figure 3 shows the quadrature component. The in-phase component comprises the spring-like and inertia-like components, whereas the damping (or velocity dependent) reactions comprise the quadrature component. If these reactions are plotted as functions of frequency, certain hydrodynamic coefficients can be identified with the slopes and intercepts of the resulting curves. For example, N_v is found from the y-intercept of the in-phase component, while $N_{\dot{r}}$ is directly related to the slope. From the slope of the damping component plot (Fig 3), the linear combination of coefficients $N_r' - N_{\dot{v}}'$ can be determined. The method of changing support points permits determination in principle at least, of the lateral forces arising from the angular displacements, velocities and accelerations, but the attainable accuracy is very limited. Instead, use of an internal strain gage type balance measuring lateral reactions is to be recommended. Appropriate instrumentation had not been developed at the time these data were taken, so that the method of changing support point was used to obtain the original data. This feature has not been exploited for the reason given above, but the original data have been presented to permit a more thorough investigation by interested persons.

It should be mentioned that one by-product of this type of

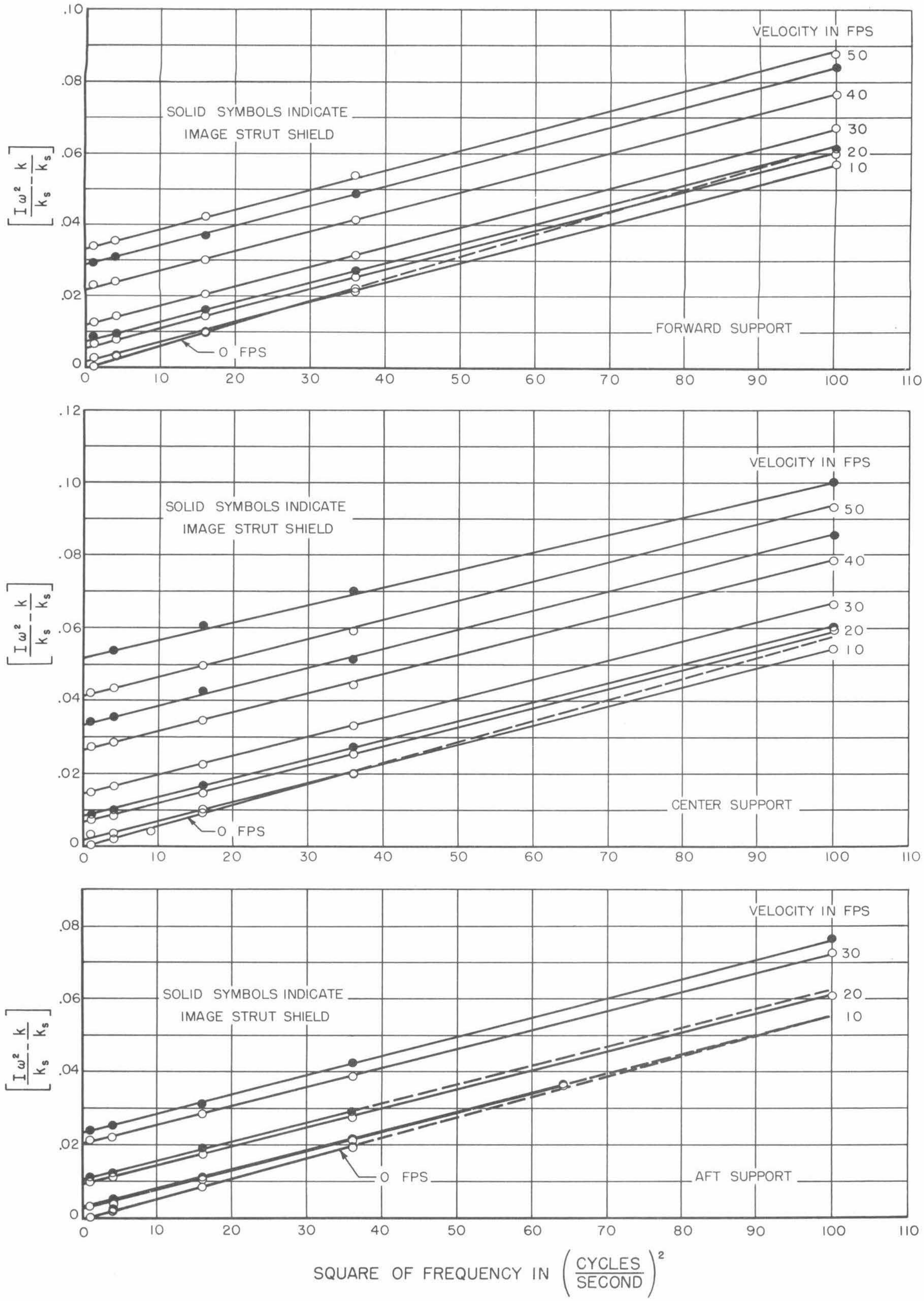

Fig. 2 - Spring-inertia (in phase) component of moment reaction on a 2-in. diameter model of the Mk-13 torpedo.

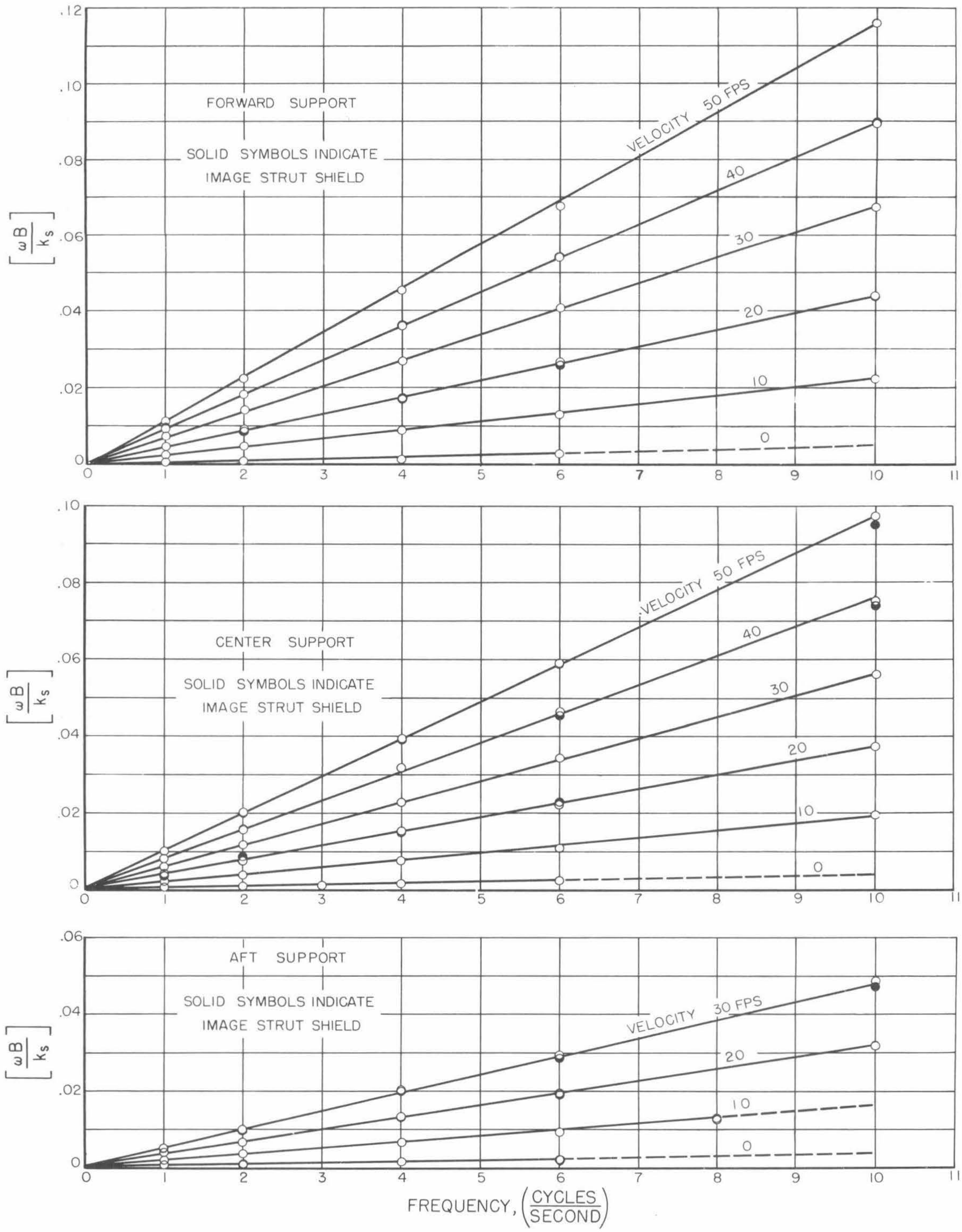

Fig. 3 - Damping (quadrature) component of moment reaction in a 2-in. diameter model of the Mk-13 torpedo.

investigation is the familiar static-moment coefficient which is directly related to N_v' and which can be found from the data reduction curves. This serves as a check on the measurements and computations leading to the final results, since it can be obtained from experiments conducted elsewhere with different types of equipment.

Results and Conclusions

The desired coefficients are presented in dimensionless form in Figures 4, 5, and 6 where they have been plotted against velocity. The sensitivity of N_v' to model support configuration should be noted, as should the dependence on velocity. Values obtained by conventional static force measurements which can be related to N_v' show similar behavior. The three curves represent faired values derived from the processed data points and corrected for the estimated effect of the spindle shield. This correction was made by assuming that the image spindle shield contributed as much influence as did the support spindle shield.

Figure 5 shows the computed value of N_r' and, excepting for the bad points exhibited by the center-support runs, also shows the independence of fluid velocity predicted by perfect fluid theory on selected body shapes. The combined coefficient $N_r' - N_{\dot{v}}'$ is the linear combination of two separate coefficients which can be analyzed completely by employing the method outlined above but which has considerable utility in the present combined form.

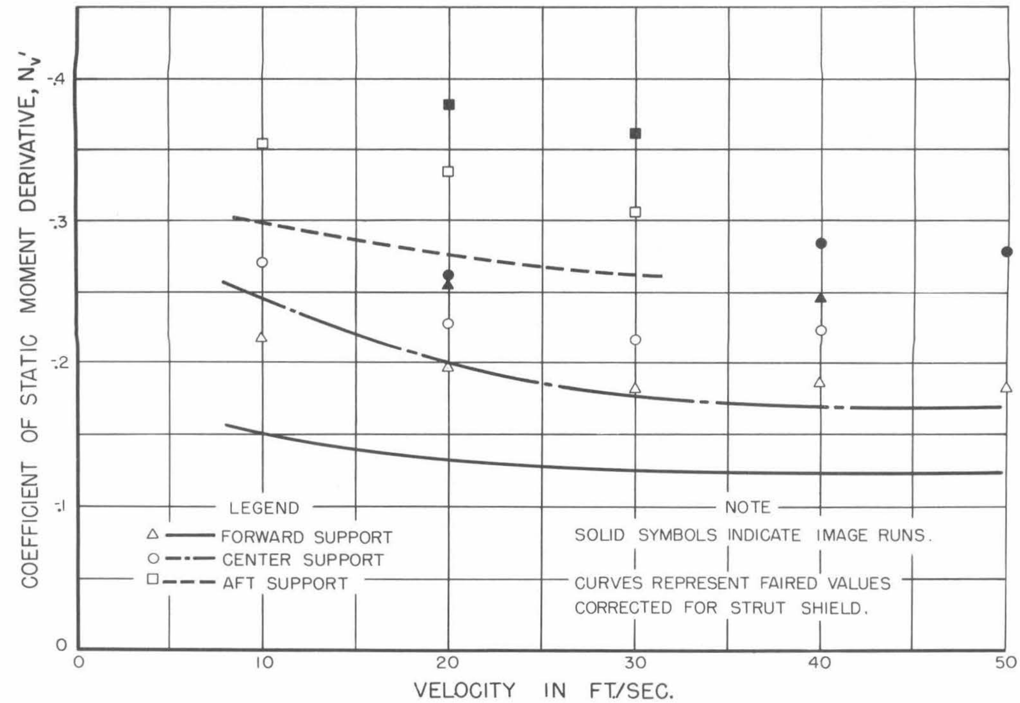

Fig. 4 - Coefficient of static moment derivative, N_v', as a function of tunnel water velocity defined with respect to point of support.

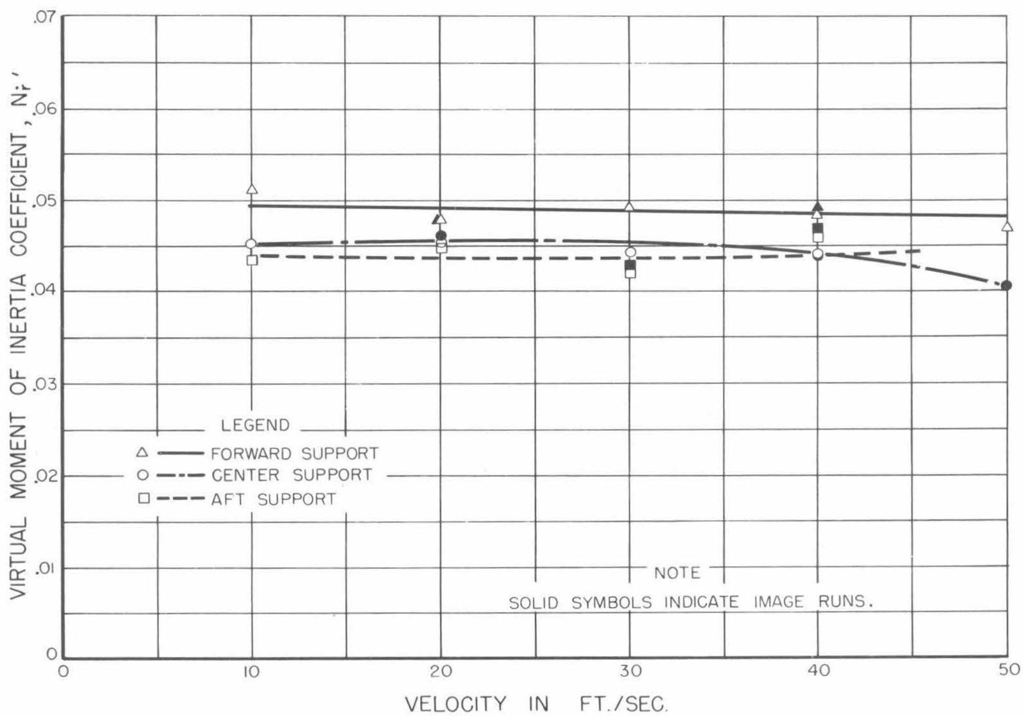

Fig. 5 - Virtual moment of inertia coefficient, $N_{\dot{r}}'$, as a function of tunnel water velocity defined with respect to point of support.

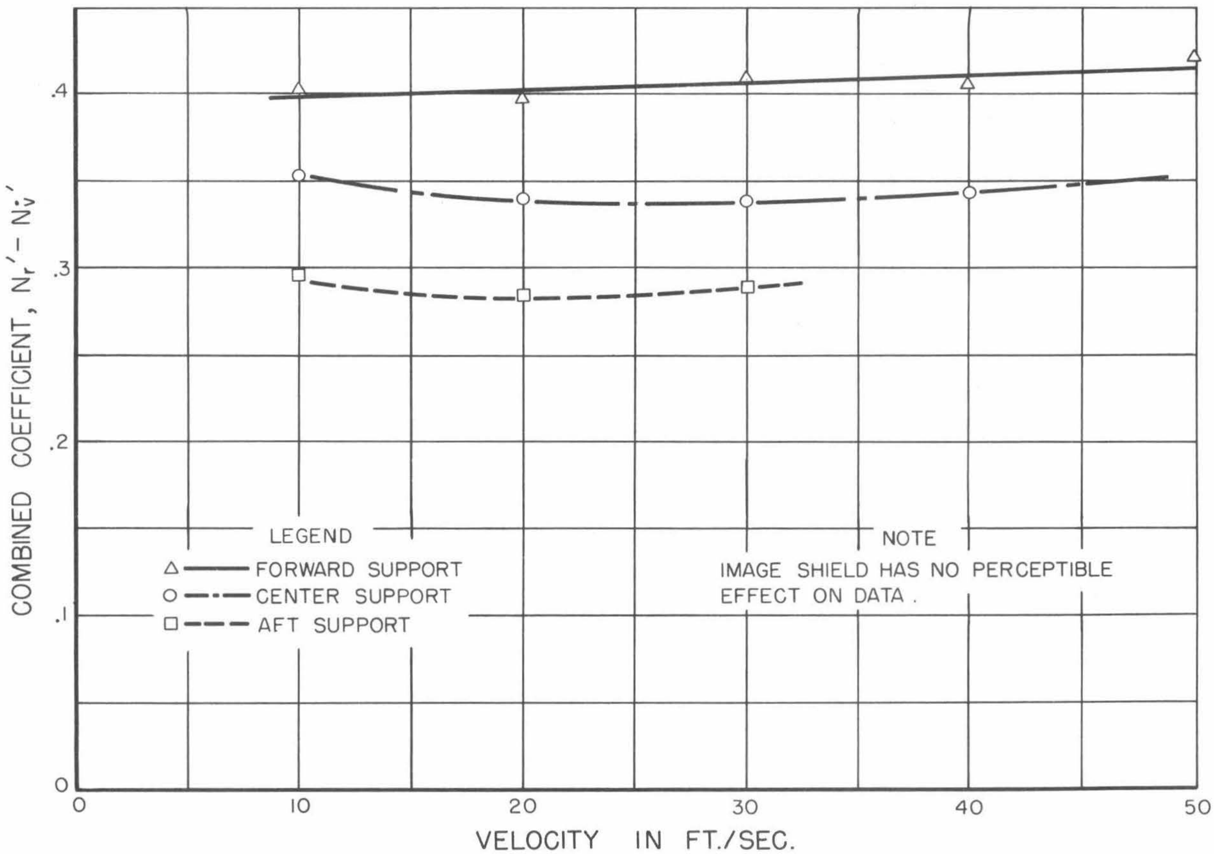

Fig. 6 - Combined coefficient, $N_r' - N_v'$, as a function of tunnel water velocity defined with respect to point of support.

List of Symbols and Abbreviations

The motion of the test body is restricted to the plane of yaw. The symbols used to describe this motion and the associated hydrodynamic reactions on the body are in the greater part identical to those recommended in the Technical and Research Bulletin N.1-5 of the Society of Naval Architects and Marine Engineers titled "Nomenclature for Treating the Motion of a Submerged Body through a Fluid". These symbols are marked with an asterisk (*) in the following list:

*	A	cross-sectional area of model in square feet.
	B	coefficient of velocity term in equation $N = -I\ddot{\beta} - B\dot{\beta} - K\beta$ which regards model-spindle assembly as single degree of freedom system undergoing forced oscillations.
	I	coefficient of acceleration term in above equation due to inertia-like hydrodynamic quantities.
	K	coefficient of displacement term in above equation due to spring-like hydrodynamic quantities.
	K_s	spring constant of support spindle to which model is fastened.
*	ℓ	length of body.
*	N	hydrodynamic moment acting on body.
*	$N_r = N_r'(1/2\rho A\ell^2 U)$	coefficient of rotary moment derivative.
*	$N_{\dot{r}} = N_{\dot{r}}'(1/2\rho A\ell^3)$	virtual moment of inertia coefficient (angular acceleration).
*	$N_v = N_v'(1/2\rho A\ell U)$	coefficient of static moment derivative.
*	$N_{\dot{v}} = N_{\dot{v}}'(1/2\rho A\ell^2)$	virtual moment of inertia coefficient (transverse acceleration).
	β =	angular displacement about yaw axis.
*	$r = \dot{\beta}$	angular velocity component about yaw axis.
*	$\dot{r} = \ddot{\beta}$	angular acceleration component about yaw axis.
*	v =	linear velocity component at right angles to longitudinal axis and in the horizontal plane.

List of Symbols and Abbreviations (cont'd)

*	v	linear acceleration component at right angles to longitudinal axis and in the horizontal plane.
*	U	velocity of origin of body relative to the fluid.
	ρ	mass density of fluid.
	ω =	$2\pi f$ circular frequency.

References

1. Stallkamp, John A., "Measurement of Dynamic Coefficients of Ellipsoids", California Institute of Technology, Hydrodynamics Laboratory Report No. E-35.4, Sept. 1956.

2. The Society of Naval Architects and Marine Engineers, "Nomenclature for Treating the Motion of a Submerged Body through a Fluid", Research Bulletin N. 1-5.

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